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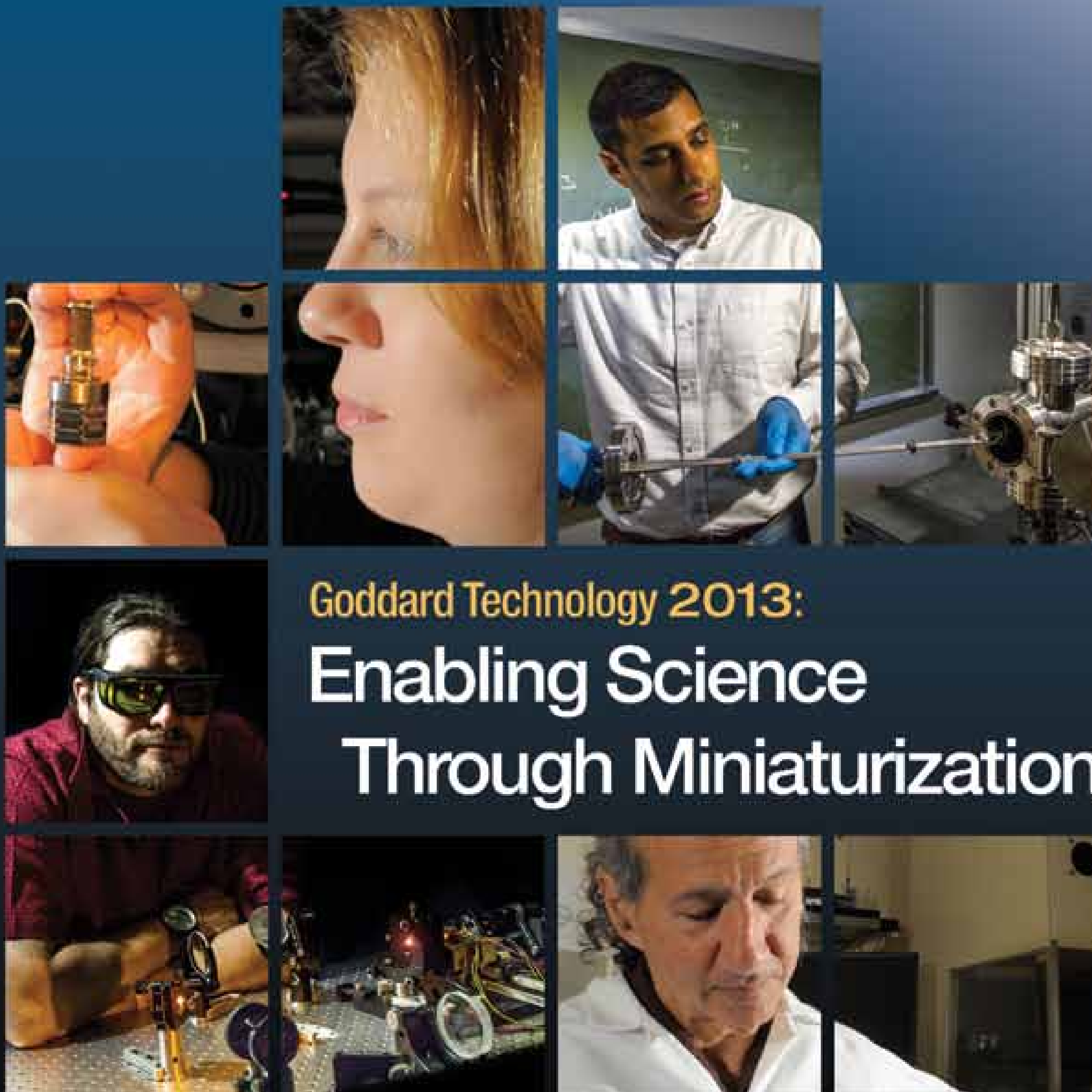
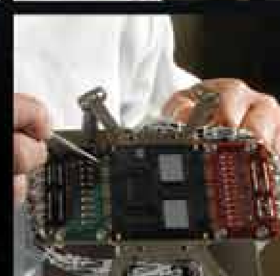


Goddard Technology 2013:
Enabling Science Through Miniaturization

A Report from the Goddard Office of the Chief Technologist



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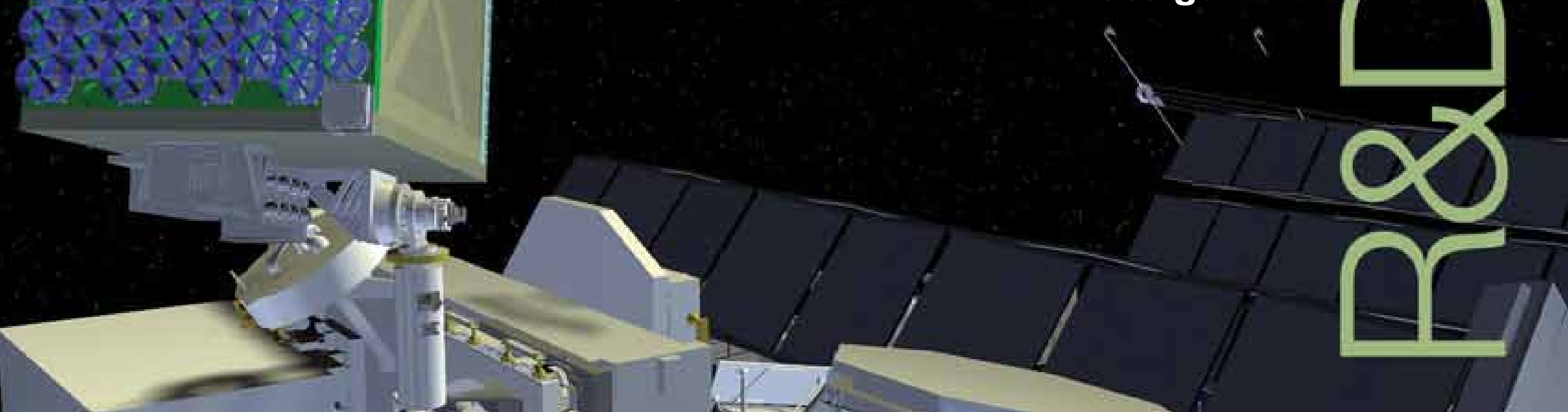


R&D Achievements

About the Cover

Goddard technologists pursued a range of technologies that could enable NASA's missions in the future — everything from new manufacturing techniques and detectors to miniaturized components needed for smaller, more capable instruments, as shown on the cover.

2013

Table of Contents

Peter Hughes
Chief Technologist

"If you want something new, you have to stop doing something old."

— Peter F. Drucker, Author and Management Consultant

Chapter One

Message from the Chief Technologist:

Delivering Innovative Results

A photo we published in the fall issue of *CuttingEdge* made an indelible impression on me. Pictured was one of our most innovative technologists standing in front of one of NASA's most successful instruments —Cassini's Composite Infrared Spectrometer. He held in his hand a palm-size device that he is convinced will one day perform the same job as the much larger CIRS, but with greater resolution and accuracy.

The juxtaposition could not have been more pronounced.

Since the invention of the first transistor in 1947, miniaturization has changed the way we live and how we do business. And it certainly has not been confined to consumer electronics.

For several years we have invested a greater share of our limited R&D dollars into shrinking the size of instrument components and systems, certain that the investment would provide the scientific community with increased science-instrument performance and less costly access to space. As our early investments showed, it did. In the winter of 2010, three Goddard principal investigators, who received Internal Research and Development (IRAD) program funding beginning in FY07 to develop their pint-size instruments, flew them aboard the FASTSAT microsatellite for a U.S. Air Force technology-demonstration mission.

Growing Emphasis on Miniaturization

The floodgates have opened since then.

Now, miniaturization is increasingly becoming more important to NASA, as evidenced by the roll out of several new smallsat technology-development efforts in FY13. Due in large part to our continued R&D investments in miniaturization, our technologists are getting noticed and winning follow-on funding under these programs to advance a range of technologies — from new propulsion techniques to more robust application-specific integrated circuits.

Included in that list is the winner of this year's "IRAD Innovator of the Year" award (see page 17). Tom Flatley is being recognized this year because of his ceaseless efforts enhancing and finding new applications for SpaceCube, a family of more powerful flight processors. His latest incarnation, the SpaceCube-Mini, is specifically designed to operate on small satellites.

We see our investment in miniaturization as vital to our future; however, it is not our only priority. We also are investing in new manufacturing techniques, materials, and other technologies that promise to give NASA orders-of-magnitude advances in data collection. This report outlines these notable successes and highlights technologies to watch in the future.

Continued Commitment to Specific Selection Criteria

When combined with our commitment to funding only those technologies that meet very particular selection criteria — in other words, map to our core lines of business and promise significant impact — we believe we have fine-tuned the recipe for success. It assures that we invest our limited IRAD and Center Innovation Fund (CIF) resources into meaningful research efforts that our review teams consider the best in their class and offer a realistic probability of follow-on funding.

Peter Drucker, the famed author and management consultant, once observed: "If you want something new, you have to stop doing something old." Doing something old would be to ignore the revolution in miniaturization, manufacturing, materials, and other technologies. As you read this report, it will become clear we have eschewed the old. Investing in and ultimately flying diminutive instruments and other technologies are the keys to assuring scientific discovery from space.

Peter Hughes
Chief Technologist

Chapter Two

The Cornerstone of Success:

Aligning Investments to Core Values, Getting Results

"It's imperative in the current environment that we realize how critical the work is that we're doing, and to not lose focus. It's hard work, but it's incredibly important."

— Chris Scolese, Center Director

FY13 proved to be an exceptionally productive year for Goddard technologists. In addition to winning two Explorer-class missions — attributable in part to past R&D investments — they continued to secure impressive levels of follow-on funding that more than compensate for our initial investment in their technologies (see page 7 for details).

Reasons for Success

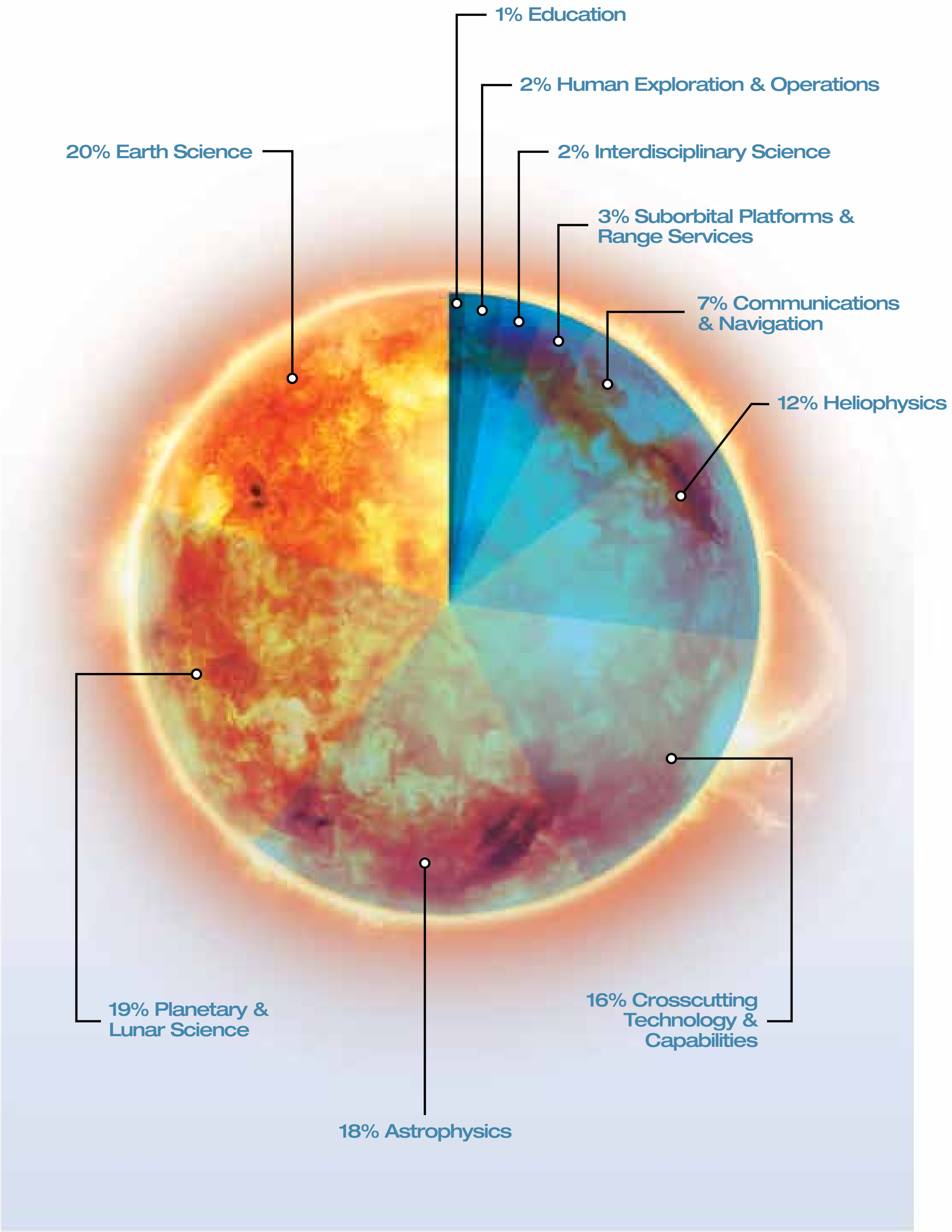
We believe the secret to our R&D success is our methodology — the focus and discipline we employ to identify investment priorities, unmet needs, and target opportunities. Although we use different selection criteria for the two investment portfolios we manage, we adhere to strict standards. Recipients of both programs must compete for their awards.

Under Goddard's Internal Research and Development (IRAD) program, for example, we fund only those efforts that map to one or more of Goddard's strategic lines of business (LOBs). In FY13, we added a new line of business — Human Exploration and Operations (HEO) — to encourage leveraged application of unique Goddard capabilities not offered elsewhere to satisfy HEO needs. Each is described on page 6.

For NASA's Center Innovation Fund (CIF), we award research dollars only to proposals that demonstrate technical merit, feasibility, relevance, and value to NASA. All are highly innovative, crosscutting, and considered early stage in their development. Many also leverage partner resources, as well as contribute significantly to national needs.

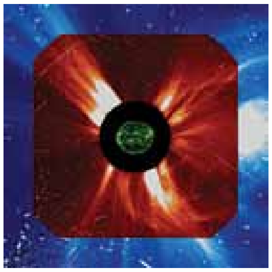
Awards in FY13

In FY13, we supported scores of IRAD and a dozen CIF proposals. The charts show the breakdown of those investments.



Astrophysics

Earth Science



Heliophysics

Planetary and Lunar Science

Suborbital Platforms and Range Services

Goddard Lines of Business: Our Roadmap to Investment Success

Astrophysics

Focuses on missions and technologies enabling the study of galaxies, stars, and planetary systems beyond our own solar system.

Communications and Navigation

Supports systems and technologies needed for responsive communications and navigation.

Crosscutting Technology and Capabilities

Addresses capabilities applicable to more than one strategic LOB, everything from nano-materials, electronics and detectors, to system architectures.

Earth Science

Supports technologies and advanced science instruments needed to observe and understand changes in Earth's natural systems and processes, including climate, severe weather, the atmosphere, the oceans, sea ice and glaciers, and the land surface.

Heliophysics

Focuses on capabilities essential for understanding solar structure and magnetic activity, solar wind, solar disturbances, and their effects on Earth's upper atmosphere.

Human Exploration and Operations

Supports infusion of science and enabling capabilities and technologies into human exploration.

Planetary and Lunar Science

Supports technologies to explore the solar system, particularly instruments for landers and orbiting spacecraft.

Suborbital Platforms and Range Services

Supports systems typically used to place payloads into suborbital attitude, including sounding rockets, balloons, manned and unmanned aircraft, and CubeSats. Range services include assets for conducting, launching, and operating missions.

Chapter Three

The Year's Notable Achievements

"Goddard had 30 percent of these wins, which really was a good showing. Our folks really capitalized on these calls."

— Carl Adams, Assistant Chief for Technology, referring to NASA's Smallsat Technology Partnerships Program

The ultimate and most tangible measure of success is whether Goddard-developed technologies are chosen for inclusion in new mission or instrument opportunities. Another is whether the technology receives follow-on funding from external sources to continue its maturation or if other instrument developers infuse an R&D-funded technology into their own concepts.

As mentioned in other sections of this report, miniaturization has become a priority for us. A greater share of our R&D investments are being invested in technologies that will enable small-satellite missions or reduce the size and cost of instrument and spacecraft components and systems. In FY13, we saw an uptick in the number of miniaturization efforts receiving outside support.

This chapter details those accomplishments as well as others that demonstrate success, particularly in the areas of flight hardware deliveries, patent filings, and the development of enhanced testing capabilities to advance other cutting-edge technologies.

Miniaturization Takes Front and Center

Smaller is definitely getting better. Goddard's investments in efforts to reduce the size, volume, and cost of spaceflight technologies through miniaturization were rewarded in FY13. NASA's new Smallsat Technology Partnerships program, for example, selected four Goddard-university teams to advance technologies that potentially could transform small spacecraft into powerful, but affordable tools for science, exploration, and space operations.

Other Goddard technologists won berths on upcoming CubeSat missions, winning follow-on funding to get their instruments ready for flight. Here we describe some of these noteworthy efforts. Additional miniaturization efforts are described in other chapters of this report.

Smallsat Technology Partnerships

High-Rate CubeSat X-band/S-band Communications System

Teaming with the University of Colorado, Goddard engineers Gary Crum and Tom Flatley will apply field programmable gate array circuitry used in SpaceCube — a reconfigurable, hybrid-computing platform that is 10 to 100 times faster than current flight processors for science applications — to create a software-defined radio. The technology would be capable of communicating in either the S- or X-band, depending on how users program the circuitry, giving CubeSat users a much higher data rate. *(Investment Area: Communications and Navigation)*

Engineer Gary Crum holds the SpaceCube-Mini, the smallest in a family of Goddard-developed onboard processors. The other device shows the relative size of a two-unit CubeSat, whose small size makes it the perfect platform for the SpaceCube-Mini. (Photo Credit: Bill Hrybyk)

In a related development funded by the IRAD program, Principal Investigator Serhat Altunc wants to advance the state-of-art for CubeSat communications over government frequencies. Altunc is developing a white paper addressing the need to standardize flight- and ground-communications systems and the frequency over which these missions would communicate. Standardization would save time and effort, Altunc said. *(Investment Area: Communications and Navigation)*

Radiation-Tolerant, Field Programmable Gate Array (FPGA)-Based Smallsat Computer System

Flatley and Crum also are working with Montana State University to apply a next-generation commercial radiation-tolerant FPGA — the Xilinx Virtex-7 — on SpaceCube. By marrying the circuitry to Goddard-developed algorithms that detect and correct radiation-induced upsets, SpaceCube is ideal for science investigations because it can provide an order-of-magnitude improvement in computing power over current solutions. *(Investment Area: Communications and Navigation)*

Mini Fourier Transform Spectrometer for CubeSat-Based Remote Sensing

Shahid "Ish" Aslam holds his spectrometer-on-a-chip, which, if fully developed, could carry out the same science as the Goddard-built Composite Infrared Spectrometer shown in the background. (Photo Credit: Chris Gunn)

Technologist Shahid "Ish" Aslam teamed with retired Goddard scientist John Allen, now a research professor at Appalachian State University, to advance a potentially revolutionary Miniaturized Waveguide Fourier Transform Spectrometer. Sensitive to the mid-infrared bands, the components inside this instrument literally would fit onto a silicon wafer. *(Investment Area: Planetary and Lunar Science)*

Film-evaporation MEMS Tunable Array for Picosat Propulsion and Thermal Control

Goddard technologist Eric Cardiff and Purdue University researcher and Principal Investigator Alina Alexeenko are advancing a dual-use technology that not only could cool instruments, but also propel the tiny satellites that carry them. *(Investment Area: Crosscutting Technology and Capabilities)*

Low-Cost Access to Space (LCAS)

Scientist Shri Kanekal holds one of the solid-state detectors that will be used in the Compact Relativistic Electron and Proton Telescope slated to fly on a CubeSat. (Photo Credit: Pat Izzo)

Compact Relativistic Electron and Proton Telescope (CREPT)

Scientist Shri Kanekal won a coveted spot on a NASA-sponsored CubeSat mission and received $1.5 million to build a smaller version of an instrument now flying on NASA's Van Allen Probes. CREPT weighs just 3.3 pounds and will augment the science of its much larger predecessor and demonstrate another miniaturized capability — the SpaceCube-Mini, one of three in a family of IRAD-funded processors. *(Investment Area: Heliophysics)*

A Draper Laboratory-led team has won a berth on a small satellite to study the imbalance in Earth's energy budget. Ultimately, the team would like to launch a constellation of these tiny satellites to gather global measurements.

Veronica Pinnick, a colleague of Principal Investigator Will Brinckerhoff, holds one of the highly compact mass spectrometer rods, the heart of Brinckerhoff's Linear Ion Trap Mass Spectrometer. (Photo Credit: Pat Izzo)

In-Space Validation of Earth Science Technologies (InVEST)

Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN)

A mission that received NASA and Goddard R&D funding won a berth on a small satellite to explore the imbalance in Earth's energy budget. The Draper Laboratory-led team, which also includes significant Goddard involvement, will build a new type of radiometer and equip it with a next-generation detector made of carbon nanotubes. RAVAN will pave the way for a constellation of similarly equipped nanosatellites that will globally measure the amount of solar energy reflected by Earth and the amount emitted back to space as infrared radiation or heat.

(Investment Area: Earth Science)

Maturation of Instruments for Solar System Exploration (MatISSE)

Linear Ion Trap Mass Spectrometer (LITMS)

NASA's Maturation of Instruments for Solar System Exploration Program awarded Principal Investigator Will Brinckerhoff $3 million to advance a miniaturized LITMS capable of in-situ characterization of a wider range of complex organic and inorganic compounds locked inside Martian rock and other extraterrestrial samples. The highly compact instrument takes advantage of significant developments by a Goddard team helping to build the Mars Organic Molecule Analyzer-Mass Spectrometer.

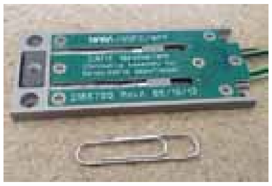
(Investment Area: Planetary and Lunar Science)

Air Force University NanoSat Program

Instrument for Small Satellite Opportunities

In FY13, Goddard researcher Georgia de Nolfo used her IRAD funding to complete an instrument prototype to measure gamma rays, neutrons, and energetic particles for small satellite platforms. In February 2014, she is expected to deliver the prototype instrument to New Mexico State University, which is building the Air Force-funded smallsat. The low-power, lightweight double-scatter spectrometer is equipped with more modern scintillator and readout technology and will demonstrate the new technology for other smallsat opportunities.

(Investment Area: Astrophysics)



Principal Investigator Luis Santos Soto has developed the Diminutive Assembly for Nanosatellite deployYables (DANY), a mechanism to release small solar panels and antennas. In FY13, he filed a patent application for his technology.

Other Flight Demonstrations

Miniture Release Mechanism

Principal Investigator Luis Santos Soto used FY13 IRAD funds to build the Diminutive Assembly for Nanosatellite deploYables (DANY) mechanism to release smallsat solar panels and antennas. At 0.188 inches, it is the only all-in-one system that fits into the external-volume allocations of CubeSats, saving valuable internal space for other subsystems. Santos Soto, who has successfully deployed DANY 15 times during a zero-gravity flight in Houston in November 2013, plans to fly the technology on a sounding-rocket flight later in FY14 to increase its technology-readiness level to seven. He has filed a patent application for his technology and is now working with NASA to identify companies interested in producing and marketing the mechanism. *(Investment Area: Suborbital Platforms and Range Services)*

Principal Investigator Jeffrey Didion flew his EHD device aboard a sounding-rocket mission, which also included a device made via additive manufacturing.

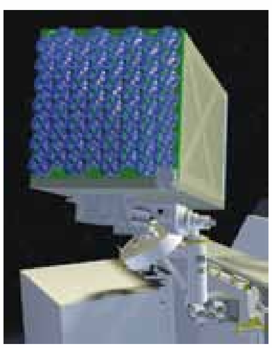
Microscale Electrohydrodynamic (EHD) Thermal and Fluid Management for Onboard Processing

Principal Investigator Jeffrey Didion, who is involved in a comprehensive, multi-year effort to advance a chip-level system for removing heat from spacecraft electronics, carried out in FY13 two technology-validation experiments, one under variable gravity and one in a sounding rocket. During the sounding-rocket flight, Didion also demonstrated another emerging technology — additive manufacturing, which technicians used to build a battery-support structure for Didion's EHD device.

Additive manufacturing, also known as 3D printing, is a technique that could revolutionize the way NASA builds spacecraft in the future and promises to advance miniaturization of instrument components. *(Investment Area: Crosscutting Technology and Capabilities)*

New Missions, Flight Opportunities, Demonstrations, and Instrument Deliveries

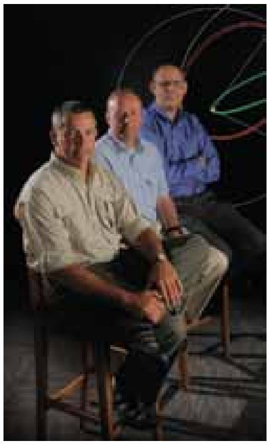
The crowning achievement of any technology program is an investment that leads to the award of a new spaceflight mission or instrument opportunity. In FY13, principal investigators won new missions and demonstrated new technologies on NASA high-altitude aircraft, sounding rockets, and scientific balloons.



This artist's rendition shows the Neutron-star Interior Composition Explorer/Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT) payload now being developed to fly on the International Space Station.

Neutron-star Interior Composition Explorer/Station Explorer for X-ray Timing and Navigation Technology (NICER/SEXTANT)

NASA's Science Mission Directorate chose a dual-purpose mission, led by Principal Investigator Keith Gendreau, as its Explorer Mission of Opportunity in FY13. NICER/SEXTANT not only will reveal the physics that make neutron stars the densest objects in nature, but also demonstrate a groundbreaking navigation technology that could revolutionize the Agency's ability to navigate to the far reaches of the solar system and beyond. *(Investment Area: Astrophysics and Communications and Navigation)*



Goddard technologists Chad Mendelsohn, Trevor Williams, and Don Dichmann used IRAD funding to analyze the orbit of NASA's newest Explorer mission, the Transiting Exoplanet Survey Satellite. The trajectory is displayed in the background. (Photo Credit: Pat Izzo)

Transiting Exoplanet Survey Satellite (TESS)

NASA also chose TESS, an Explorer-class mission that will study a large number of small planets around the brightest and closest stars in the sky. Although mission planners do not attribute the win solely to a Goddard-led analysis of the spacecraft's never-before-used orbit, they do strongly believe it contributed. Using IRAD funding, a team of Goddard engineers not only confirmed the viability of the mission's P/2 lunar-resonant orbit, but also discovered that the orbit afforded a greater number of actual launch days than originally envisioned. *(Investment Area: Astrophysics)*

Wallops Arc-Second Pointer (WASP)

The Wallops Balloon Program Office, which developed a new way to point balloon-borne stratospheric telescopes with arc-second accuracy, successfully employed the technology during its first science mission in 2013. The team that developed the highly configurable WASP also received $2.4 million from NASA's Science Mission Directorate to further enhance WASP so that scientists can use it as a standard support system, which frees them to focus on instrument development and not pointing systems. *(Investment Area: Suborbital Platforms and Range Services)*

Defense Department Space Test Program (STP)-H4

SpaceCube 2.0 — one in a family of more powerful flight processors advanced by this year's IRAD Innovator of the Year Tom Flatley (see page 17) — made its maiden voyage on the military's STP-H4 instrument platform now operating on the International Space Station in FY13. Also onboard were three other IRAD-funded, miniaturized technologies: the electrohydrodynamic (EHD) thermal-control experiment (see page 10), the Winds-Ion-Neutral Composition instrument, and Firestation, which is studying lightning in Earth's upper atmosphere. *(Investment Area: Crosscutting Technology and Heliophysics)*

This image shows circuitry inside SpaceCube 2.0, which is flying on the military's STP-H4 instrument platform now operating on the International Space Station. This is the maiden voyage for SpaceCube 2.0, one in a family of advanced onboard processors.

Navigator GPS

It was a big year for the creators of the Navigator GPS receiver. In addition to delivering a flight model to NASA's Global Precipitation Measurement mission and the Magnetospheric Multiscale mission, the team licensed the technology to an Arizona-based aerospace company — a success by any measure. However, the technology's creators are not resting on their laurels. With the trend toward smaller-size missions and demand for more capabilities, the team in FY13 began modernizing Navigator by adding new GPS signal capabilities, reducing its size and enhancing its sensitivity. *(Investment Area: Communications and Navigation)*

Three Goddard divisions successfully demonstrated NASA¹s first wide-field soft X-ray camera for studying "charge exchange.

Principal Investigators Gerry Heymsfield and Lihua Li debuted their improved HIWRAP dual-frequency Doppler radar in the fall of 2013. (Photo Credit: Bill Hrybyk)

Murzy Jhabvala is shown here with the backup QWIP focal-plane assembly. (Photo Credit: Pat Izzo)

This artist¹s rendition shows NASA's Soil Moisture Active Passive spacecraft, which will carry a Goddard-developed "smart" radiometer.

Sheath Transport Observer for the Redistribution of Mass (STORM)

Three Goddard scientists teamed in FY13 to successfully demonstrate on a Black Brant sounding rocket NASA's first wide-field soft X-ray camera for studying "charge exchange," a poorly understood phenomenon that occurs when the solar wind collides with Earth's exosphere and neutral gas in interplanetary space. The unique collaboration involved Goddard's Heliophysics, Astrophysics, and Planetary Science Divisions, and resulted in the first successful demonstration of the STORM instrument, which employed the emerging lobster-eye optics that focuses light from many different angles into a single image.
(Investment Area: Astrophysics, Heliophysics, and Planetary Science)

High-altitude Imaging Wind and Rain Profiler (HIWRAP)

Principal Investigators Gerry Heymsfield and Lihua Li debuted their new and improved HIWRAP dual-frequency conical-scanning Doppler radar during this fall's Hurricane and Severe Storm Sentinel mission. The IRAD-funded instrument, which the team made more effective at high altitudes, gathered data on raindrops and ice particles during its flight aboard an unmanned Global Hawk, one of two aircraft that participated in the month-long mission studying Atlantic hurricanes. *(Investment Area: Earth Science)*

Quantum Well Infrared Photodetector (QWIP)

QWIP, which made its debut on the Landsat Data Continuity Mission launched in February 2013, proved its mettle and is now collecting infrared signals in two thermal bands to monitor the ebb and flow of land-surface moisture levels and the health of vegetation. Now that the technology is flight-proven, scientists are eyeing next-generation QWIP arrays for advanced instrumentation (see page 21).
(Investment Area: Crosscutting Technology and Capabilities)

L-Band Radiometer

Goddard technologists Damon Bradley and Jeff Piepmeier delivered in FY13 a "smart" microwave radiometer that mitigates "noise" caused by radio interference. The instrument is now being integrated onto NASA's Soil Moisture Active Passive spacecraft, which NASA plans to launch in late 2014. The instrument took 12 years to develop and is expected to return relatively clean data needed to help crack an as-yet unsolved climate mystery: the location of the sinks that take up carbon emissions.
(Investment Area: Earth Science)

Follow-On Funding to Advance Technology-Readiness Levels

The IRAD and CIF programs are not meant to provide cradle-to-grave support. Therefore, a key success metric is whether principal investigators succeed in securing follow-on funding to further advance their technologies. In FY13, these funding sources came from NASA's Space Technology Mission Directorate (STMD), NASA's Innovative Advanced Concepts (NIAC) program, Instrument Concepts for Europa Exploration (ICEE) program, the Earth Science Technology Office (ESTO), and the Astronomy and Physics Research and Analysis (APRA) program, among others.

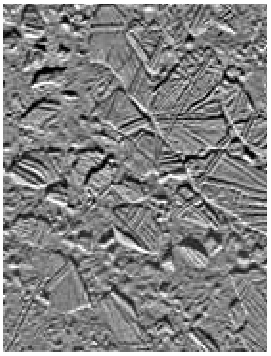
This image, snapped by a Russian spacecraft, shows the surface of Venus, one of the possible targets for an adaptive, deployable entry and placement technology that Principal Investigator Lori Glaze is developing with the Ames Research Center.

Adaptive, Deployable Entry and Placement Technology (ADEPT)

Principal Investigator Lori Glaze received nearly $1.4 million from NASA's Game Changing Development Program to design and build the deployment mechanisms for a next-generation atmospheric entry technology appropriate for a future planetary mission. While Ames is leading the effort, Glaze and her team will build the structure that connects ADEPT to a potential payload. She also is responsible for helping develop the testing plan and testing the technology at Goddard facilities. *(Investment Area: Planetary and Lunar Science)*

Soft X-ray Spectroscopy

Under a five-year award from NASA's APRA program, Principal Investigator Will Zhang won $1.6 million to build a new X-ray spectrometer, which will be equipped with a more powerful telescope that is expected to offer unprecedented spectral resolution. Collaborating with the University of Iowa, which is building the instrument's telescope gratings, Zhang plans to demonstrate the spectrometer on a rocket flight from the Wallops Flight Facility. *(Investment Area: Astrophysics)*



This high-resolution Galileo image shows Europa's ice-rich crustal plates, which are about eight miles in diameter. The proposed Europa Clipper would study the oceans lying beneath the ice to determine whether the moon harbors conditions suitable for life.

Thermal Imager for Europa Reconnaissance (TIMER)

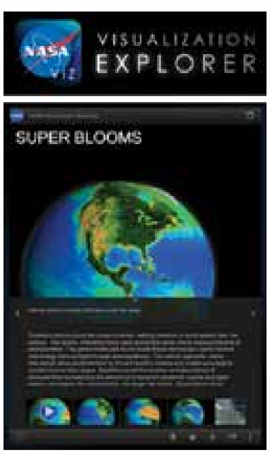
Principal Investigator Shahid "Ish" Aslam received $1.2 million from NASA's ICEE program to develop a radiometer that would detect fissures in the ice crust of Europa, one of Jupiter's moons. The instrument, called TIMER, is in contention for a berth aboard NASA's Europa Clipper, a conceptual fly-by mission to determine whether the moon harbors conditions suitable for life. *(Investment Area: Planetary and Lunar Science)*

Europa Clipper Altimeter

Another Goddard team, led by technologist Xiaoli Sun and Dave Smith, a researcher with the Massachusetts Institute of Technology, also won $600,000 in ICEE funding to develop an altimeter to measure Europa's shape and surface topography and calculate the thickness of the ice shell and the depth of the ocean. It, too, is in contention for

Goddard scientist Michael McElwain holds a lenslet array, an important component in his Prototype Imaging Spectrograph for Coronagraphic Exoplanet Studies, a tabletop-size laboratory instrument he is developing under his Nancy Grace Roman Technology Fellowship. (Photo Credit: Pat Izzo)

Cataclysmic events, such as this binary-star merger as depicted in this artist's rendition, are believed to create gravitational waves that cause ripples in space-time. A Goddard team now is advancing a potentially revolutionary technology to detect these ripples that Albert Einstein predicted.



This image shows the interface users see when using the NASA Viz, an iPad app that allows users to easily interact with images, video, and information about NASA's latest research.

Prototype Imaging Spectrograph for Coronagraphic Exoplanet Studies (PISCES)

The Nancy Grace Roman Technology Fellowship awarded Principal Investigator Michael McElwain $1 million in four-year funding to continue development of PISCES, an integral field spectrograph to be deployed on the Jet Propulsion Laboratory's (JPL) High-Contrast Imaging Testbed, a facility JPL has built to test candidate starlight-suppression technologies. McElwain's PISCES also could serve as the foundation for a future spaceflight instrument. *(Investment Area: Astrophysics)*

Atom Interferometer

The NIAC program awarded Goddard Principal Investigator Babak Saif $500,000 to mature an emerging, potentially revolutionary atom interferometer that potentially could offer scientists picometer-level sensitivity. Saif and his team are developing the atom-optics technology to detect theoretical gravitational waves. In addition, the team now is working with Earth scientist Scott Luthcke to apply the same technology to mapping tiny variations in Earth's gravity field. *(Investment Area: Astrophysics)*

GLOW Campaign

Principal Investigator Bruce Gentry won $531,000 in NASA funding to carry out a measurement campaign with Howard University using the Goddard Laboratory for Observing Winds (GLOW). The mobile direct-detection Doppler lidar system, which was created in part with IRAD funds, profiles winds in clear air from the surface into the stratosphere. Carried in a van, the instrument features a number of innovations, particularly in the Doppler receiver. *(Investment Area: Earth Science)*

NASA Viz

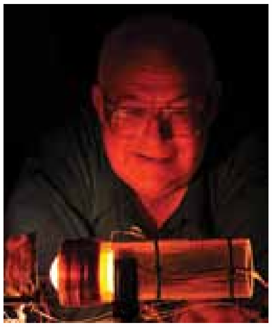
Creators of NASA Visualization Explorer received $350,000 in one-year NASA funding to continue developing content for NASA Viz, an iPad app. Rolled out a couple years ago, the app allows users to easily interact with images, video, and information about NASA's latest Earth Science research. Goddard's IRAD program provided seed funding to create and launch the application and creators say their app has only "scratched the surface" of its potential. *(Investment Area: Earth Science)*

Strategic Collaborations, Patents, and Commercial Infusion

Research and development can be expensive, often taking years to produce meaningful results. That is why Goddard innovators are encouraged to seek partnerships to advance particularly viable new ideas. Ultimately, these strategic partnerships can lead to the infusion of cutting-edge technologies into commercial products. In FY13, Goddard innovators forged strategic partnerships with a variety of organizations to help offset the costs of R&D and worked with private industry to commercialize technologies. They also filed patent applications for their work.

Adaptive Trajectory Design (ATD)

ATD is an original and unique concept for quick and efficient end-to-end trajectory designs, particularly those in Cis-lunar and Earth-Moon libration points. The tool, developed by Principal Investigator Dave Folta, is now being considered for commercial applications, and, in fact, one company Decisive Analytics Corp., has requested that NASA allow it to insert ATD into the software it is developing to enhance Goddard's General Mission Analysis Tool, also known as GMAT. *(Investment Area: Communications and Navigation)*



Principal Investigator Fred Minetto is bathed in a red glow produced by an electron gun, a key technology in a novel technique for cleaning mirrors and lenses. (Photo Credit: Pat Izzo)

Cleaning Mirrors and Lenses with Electrons

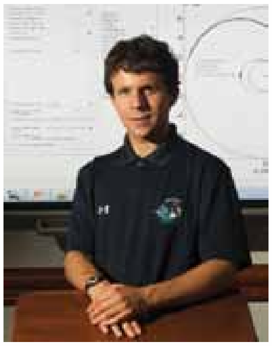
Principal Investigator Fred Minetto, who has created a novel way to clean mirrors and lenses, used FY13 IRAD funding to develop a one-atmosphere electron gun capable of sustaining a 0.9-micro ampere beam current, which would enable its use in cleanrooms. The technology is a spin-off of an electron gun and Fractal wand he developed for potential use in space. In FY13, Minetto filed a patent application for his technology and is awaiting the award of two other patents related to the space-based device. *(Investment Area: Crosscutting Technology and Capabilities)*

Technology Development for Multi-Axis Attitude Control

Principal Investigator Alvin Yew achieved a major milestone in his effort to develop an improved spacecraft pointing system for small satellites. Through a Space Act Agreement, he joined forces with Northrop Grumman to further develop the technology. In particular, the team will develop a proprietary system to achieve three-sigma, arc-second, multi-axis pointing, while consuming less than 0.5 watts of power. *(Investment Area: Suborbital Platforms and Range Services)*

Critical Support Capabilities and Materials

Some technologies are not meant to provide scientific data; their sole purpose is to provide technologists and others with capabilities that assist them in their quest to develop advanced instruments or to interpret data needed by the public. These capabilities include everything from specialized laboratories and instrument subsystems to new materials that meet specific spaceflight needs.



Jacob Englander has created an on-orbit determination tool that makes it faster to determine trajectories for spacecraft traveling to hard-to-reach destinations. The image projected in the background shows the trajectory to Odysseus, a Trojan asteroid. While not associated with any mission or mission proposal, Englander used his tool to create the design. (Photo Credit: Pat Izzo)

Low-Thrust Trajectory Design

Principal Investigator Jacob Englander has developed a fully automated tool that gives mission planners a preliminary set of detailed directions for efficiently steering spacecraft to hard-to-reach interplanetary destinations. The Evolutionary Mission Trajectory Generator, which operates on a standard desktop computer, is unique. With this tool, mission planners need only to input key parameters, such as the spacecraft's point of origin and final destination, and the tool creates a preliminary orbit — a development that will save time and money. *(Investment Area: Communications and Navigation)*

Optical Navigation (OpNav) Measurement Processing

Under his FY13 IRAD, Principal Investigator Kenneth Getzandanner developed OpNav software tools to support next-generation interplanetary and small-body missions, including those to asteroids, comets, and moons. Getzandanner added the OpNav measurement-processing technology, as well as a high-fidelity camera, to NASA's current orbit-determination software — GEODYN. The new capability now means that geophysicists and others can process optical navigation measurements in scientific analyses and spacecraft operations. *(Investment Area: Planetary and Lunar Science)*

Technologist Vivek Dwivedi, who has distinguished himself as the go-to engineer for atomic layer deposition, has assembled a new reactor that he plans to use for thin-film experimentation. He is inserting the quartz crystal microbalance, one of the technologies included in his "virtual toothpick." (Photo Credit: Bill Hrybyk)

Virtual Toothpick

Technologist Vivek Dwivedi has created a reactor and a suite of monitoring tools that technologists may use when experimenting with thin films and testing whether they are fully "baked." The thin-film deposition technique, called atomic layer deposition (ALD), offers an advantage over other deposition techniques because it can deposit films inside pores and cavities, giving ALD the unique ability to coat in and around three-dimensional objects. The suite of monitoring tools, which Dwivedi calls the "virtual toothpick," includes a modeling program to determine how much gas to deposit on the substrate or component, a quartz crystal microbalance to actually measure the thickness of the film being deposited, and a residual gas analyzer that detects the gases that flow through the reactor. *(Investment Area: Crosscutting Technology and Capabilities)*

Technologist Tom Flatley was chosen to receive this year's "IRAD Innovator of the Year" award due to his pioneering work advancing the SpaceCube technology. (Photo Credit: Pat Izzo)

Tom Flatley and the SpaceCube development team have worked tirelessly to find applications and develop new products under the SpaceCube brand.

Shown here is the SpaceCube-Mini, along with two other devices that show the relative sizes of tiny satellites or CubeSats on which SpaceCube is slated to fly in the future. (Photo Credit: Bill Hrybyk)

Chapter Four

A Year of Accolades for FY13 IRAD Innovator of the Year, Tom Flatley

Goddard engineer Tom Flatley, who has spent the past several years enhancing the Goddard-developed SpaceCube flight processor and finding new applications for the more powerful technology, has received his share of accolades. In FY13, he added another to his curriculum vitae.

The Goddard Office of the Chief Technologist (OCT) chose him as its 2013 "IRAD Innovator of the Year," a prize it awards annually to those who exemplify the best in innovation and contribute to NASA's mission and goals.

"We are truly fortunate that Goddard employs so many highly capable technologists. However, it makes it difficult selecting the one person who personifies the attributes that make our Internal Research and Development program one of NASA's most effective," said Chief Technologist Peter Hughes, in his announcement of Flatley's selection. "But after carefully reviewing the nominees' qualifications, the decision as to whom to honor this year ended up being straightforward."

Although Flatley was acknowledged in 2009 with an honorable mention, Hughes said Flatley's ceaseless efforts to enhance SpaceCube and find new applications for this powerful technology made him the standout this year.

First demonstrated in 2009 during the Hubble Servicing Mission-4, SpaceCube has since evolved into a family of products that offers science missions an alternative for science-data processing. Due in large part to his stewardship, SpaceCube 1.0, 1.5, 2.0, and the Mini have all flown or are scheduled to fly on a variety of spaceflight missions, including the Defense Department's most recent Space Test Program-H4 mission deployed now on the International Space Station.

"Flatley has given NASA a much-needed alternative, a more robust computing platform that not only is nearly as reliable as the fully radiation-hardened RAD750 for science applications, but also capable of handling the significantly higher data rates of current and planned missions. The technology's relatively fast evolution from laboratory breadboard to spaceflight is a testament to his can-do spirit and vision," Hughes said.

As in past years, Flatley was presented with the award at OCT's annual Poster Session —"Goddard Technology: Enabling Science Through Innovation" — in early December 2013 (see page 25).

Chapter Five

Technologies to Watch

Research and development is a high-risk endeavor. In some cases, the research does not yield the expected outcome or result. In others, the principal investigator achieves precisely what he or she set out to accomplish. Here we spotlight just a few R&D-funded efforts that are early-stage, often higher-risk technologies that could one day result in Goddard creating new opportunities and helping NASA carry out its science and exploration missions.

Astrophysics

Next-Generation X-ray Detectors for a Probe-Class Mission

Principal Investigator James Chervenak has designed, produced, and tested a prototype of a more capable X-ray detector array. In October 2013, Chervenak delivered the prototype array for testing. He believes the technology demonstration will help influence future mission proposals.

Electro-Thermal Characterization of a Multi-Moded Bolometer

Work continues on next-generation multi-moded detectors for the Primordial Inflation Explorer (PIXIE), a conceptual mission that would measure gravitational waves through their imprint on the polarization of the cosmic microwave background. Principal Investigator Al Kogut says the technology has advanced substantially over the past two years.

High-Reflectance Silicon Dielectric Mirrors for Infrared Astronomy

Developing infrared optics capable of operating under cryogenic conditions is a critical need for NASA. Principal Investigator Kevin Denis has designed a new fabrication technique for creating highly reflective multi-layer dielectric coatings suitable for optics sensing the mid- to far-infrared wavelength bands. The technology could be used in conjunction with a number of more capable detectors, including the Backshort Under Grid detector array developed by Principal Investigator Christine Jhabvala.

Communications and Navigation

Multi-Channel Demodulator for Small Satellites

In another effort to miniaturize critical spacecraft components, Principal Investigators Wing Lee and Wai Fong have begun developing a technology that would allow simultaneous communications between multiple femtosats operating as a constellation. Such a technology would allow “daughter” small satellites to transmit data to a mother satellite, which would then downlink the data to ground stations, thereby reducing the complexity of ground-station networks.

Laser Timing and Navigation Characterization

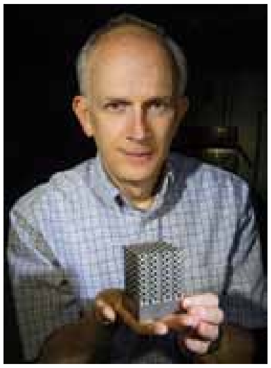
One-way laser ranging is one of the most accurate measurement techniques; however, clock errors can occasionally mar the data. Principal Investigator John Gaebler is attempting to improve the absolute timing of the outgoing laser pulses from Goddard's satellite laser-ranging stations. Such an improved capability would help mission planners more precisely determine the orbits of their spacecraft. It also could benefit gravity mapping.

GSFC High-Rate Ka-Band Technology End-to-End Demonstration

Principal Investigator Jacob Burke used his FY13 IRAD funding to reduce the real and perceived risks of using high-rate, 26 GHz (Ka-Band) communication links. Although a demonstration on the International Space Station was derailed due to funding issues, Burke said the effort has piqued interest in using this frequency and could lead to future proposals.

Crosscutting Technology and Capabilities

DMLS Lightweight Optical Bench



Principal Investigator Tim Stephenson holds the world's first Invar structure produced by direct metal laser sintering, a 3D manufacturing technique. (Photo Credit: Bill Hrybyk)

Another important research area that could greatly affect science-instrument development is the use of 3D manufacturing. In FY13, Principal Investigator Tim Stephenson contracted with Electro Optical Sciences of North America to develop the world's first Invar structure produced by direct metal laser sintering (DMLS), a 3D manufacturing technique. Stephenson's goal is to eventually create a 3D-printed Invar optical bench that would be nearly immune from shrinkage or expansion due to extreme changes in temperature.

Efficient Radiation Shielding Through 3D Printing

Principal Investigator Jean-Marie Lauenstein also is investigating the use of 3D manufacturing. In particular, she is interested in creating radiation shielding to protect sensitive spacecraft electronics from ionizing radiation. Current shielding techniques are effective; however, they do add mass to a system. Under her concept, radiation shielding would be applied as customized 3D-printed structures, applied to particularly vulnerable devices, thereby cutting down on mass. Research is continuing.

Common Customizable Instrument Electronic Packages

Under two separate IRAD awards, principal investigators began work on a common customizable instrument electronic package, called MinE Pack, which could result in greater efficiencies when developing instrument electronics for Heliophysics and Planetary missions. Principal Investigator George Suarez addressed the requirements and baseline architectures for such a technology, while his colleague, Beth Paquette, examined possible packaging for the MinE Pack device. The two technologists believe that MinE Pack could increase Goddard's competitiveness, while decreasing the cost of spacecraft electronics.

Australia's Melbourne Centre for Nanofabrication used atomic layer deposition to apply a catalyst layer on a three-dimensional instrument component. Principal Investigator John Hagopian then successfully grew carbon nanotubes on the device, and in doing so, proved that carbon nanotubes could be applied to complex spacecraft components. (Photo Credit: MCN)

Carbon Nanotubes

Principal Investigator John Hagopian, who is advancing the use of a carbon-nanotube coating for a range of spaceflight applications, achieved another milestone in FY13. He and his team demonstrated that they could grow a uniform layer of carbon nanotubes through the use of another emerging technology called atomic layer deposition, led by IRAD awardee Vivek Dwivedi (see page 16). The marriage of the two technologies now means that NASA can grow nanotubes on three-dimensional components, such as complex baffles and tubes commonly used in optical instruments.

Radiation-Hardened Compact Multi-Channel Digital-to-Analog Converter

Principal Investigator George Suarez developed a radiation-hardened application-specific integrated circuit for a compact multi-channel digital-to-analog converter. The effort is aimed at reducing the size, mass, and power of instrument electronics, which would make Goddard scientists more competitive for future CubeSat missions.

Lowpass Filters

Ari Brown devised a tidier, less weighty technique to block heat from contaminating measurements collected by ultra-sensitive infrared sensors. (Photo Credit: Pat Izzo)

Preventing stray light or heat from contaminating the measurements of ultra-sensitive infrared detectors used to be a cumbersome, messy affair involving the application of a gooey, cement-like material around the electronic wiring that delivered this unwanted signature. Goddard technologist Ari Brown has devised a compact array of superconducting, lowpass filters embedded on a silicon substrate. In testing, Brown has demonstrated that these chip-like devices allow electrical signals from an instrument's electronics to travel to the detectors, while blocking the heat that typically propagates along the electrical wiring.

Earth Science

Dual-Frequency Cloud Radar System

Principal Investigator Gerry Heymsfield, the creator of the High-altitude Imaging Wind and Rain Profiler that flew on the FY13 Hurricane and Severe Storm Sentinels (HS3) mission this year (see page 12), is now developing a new dual-frequency, W- and Ka-band cloud radar, similar to one planned for NASA's proposed Aerosol-Chemistry-Ecology (ACE) mission. In addition, an airborne version of the new radar could be used as an ACE simulator system.

Meanwhile, Heymsfield's colleague, Lihua Li, used his FY13 IRAD — Frequency Diversity Technique for Spaceborne Radar Doppler Measurements — to develop and evaluate a new technique to extend the Doppler range of remote-sensing radars. The technology potentially could benefit the ongoing HS3 mission and the ground-validation system for NASA's Global Precipitation Measurement mission.

Global Hawk Airborne Precursor

In another effort to reduce the risk, cost, and size of future instruments, Principal Investigator Haris Riris is designing a highly accurate, compact airborne lidar to measure the column abundance of methane and carbon dioxide. The miniaturized instrument would be suitable for carbon-cycle field studies aboard NASA's Global Hawk aircraft, calibration-validation campaigns, and in support of NASA's ASCENDS (Active Sensing of CO2 Emissions over Nights, Days, and Seasons) mission.

Principal Investigator Haris Riris is designing a highly accurate, compact airborne lidar to measure the column abundance of methane and carbon dioxide. The instrument would fly on aircraft such as the Global Hawk pictured here.

Lidar Remote Sensing of Atmospheric Trace Gases Using Dispersion

In another ASCENDS-enabling technology, Principal Investigator Jim Abshire has begun early-stage work on a new lidar technique to remotely measure atmospheric trace gas column densities using a laser that remotely senses the dispersion in the gas's index of refraction. The potential payoff is a high-performing lidar that also could fly on other future Earth Science-related missions.

Development of a Strained-Layer Superlattice (SLS) Infrared Detector Camera

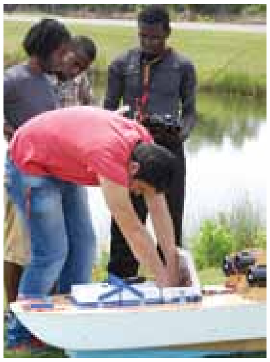
SLS detectors are a new class of devices, which may eventually provide substantially higher quantum efficiencies than existing quantum well-based (QWIPS) detectors now flying on the Landsat Data Continuity Mission (see page 12). Principal Investigator Murzy Jhabvala, who created the QWIPs technology, believes SLS could provide a competitive alternative to the current state-of-the-art mercury cadmium telluride detector arrays.

This image shows the camera equipped with strained-layer superlattice detectors, a next-generation sensing technology that could provide a competitive alternative to the current state-of-the-art mercury cadmium telluride detector arrays.

LabNotes

Principal Investigator Carl Hostetter is taking advantage of the growing popularity of hand-held and mobile computing devices. In his FY13 IRAD, Hostetter began developing LabNotes, an iPod/iPhone app that could command, control, and acquire data for the mini-Laser Heterodyne Radiometer (mini-LHR), a portable instrument that measures carbon dioxide in atmospheric columns. Hostetter said he has demonstrated the app at lower data rates and believes he will eventually fully support the mini-LHR and other instruments.

Principal Investigator Carl Hostetter is developing an app that could command, control, and acquire data for Earth Science instruments.



Students at the University of Maryland Eastern Shore prepare the Remotely Operated Vehicle for Environmental Research (ROVER) "X-2" prototype for a depth measurement mission in a campus pond. Since starting the ROVER program, two ROVER team members won third-place awards in the Undergraduate Robotics Competition sponsored by the American Society of Mechanical Engineering.

Education

Though education is not one of Goddard's official lines of business, we do set aside resources for principal investigators who apply technology for educational purposes.

Remotely Operated Vehicle for Environmental Research (ROVER)

ROVER is a remotely operated aquatic system involving students and faculty at the University of Maryland Eastern Shore (UMES). Principal Investigator Geoff Bland designed and fabricated a prototype system and a UMES team is replicating the ROVER to gather measurements in coastal waters.

Sensors, Circuits, and Satellites

Principal Investigator Bryan Duncan created an innovative "plug-and-learn" electronics kit, an activity booklet, and lessons — an all-in-one resource to educate parents, teachers, informal educators, and children about the fundamentals of electromagnetic energy and its relationship to remote sensing and NASA science.

Heliophysics

Miniaturized Ion and Neutral Spectrometer for CubeSats

Goddard's Heliophysics Division — a center leader in the effort to miniaturize instruments and make wider use of small satellites — is designing, building, and calibrating a miniature ion and neutral mass spectrometer suitable for three-unit-size CubeSats. The spectrometer includes a pair of time-of-flight sensors: one for ions, the other for neutrals. Both sensors share electronics and the instrument's mechanical housing. The design is extendable to include neutral winds. The two-year effort will culminate in FY14, with a ready-to-launch instrument.

Principal Investigator Diego Janches and his team are advancing the world's first spaceborne sodium lidar for mesospheric studies. (Photo Credit: Bill Hrybyk)

First Spaceborne Sodium Lidar

Although sodium lidars have been used for decades in ground-based measurements of Earth's mesosphere, scientists have never flown such an instrument in space. Principal Investigator Diego Janches is now advancing one under Goddard's IRAD program. Ultimately, he believes the world's first spaceborne sodium lidar would reveal even greater details about this poorly understood region of Earth's atmosphere.

Time-of-Flight Chip

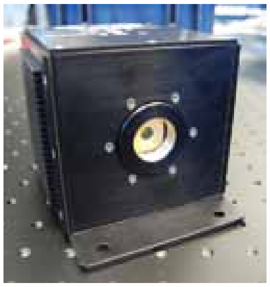
Principal Investigator Nikolaos Paschalidis also is developing a time-of-flight system-on-a-chip that enables a whole new class of instruments, including particle/mass analyzers, photon/ENA imagers, and laser altimeters. In FY13, Paschalidis tested and characterized prototype chips and says the technology already is baselined on several flight projects and proposals.

Radiation-Hardened Ion Mass Spectrometer

Goddard's Heliophysics Division — a center lead in plasma instruments — is designing, building, and calibrating a plasma composition instrument capable of separating major and minor species in extreme-radiation environments dominated by relativistic electrons. The development led to special tools that also could be applied to the design of highly hardened next-generation spacecraft.

A Compact Coronagraph Design for Heliophysics Missions

The Heliophysics Division, building on its long experience with solar coronagraphs, is pioneering a novel, compact, and affordable design that could be deployed on a variety of platforms, including CubeSats or other small satellites, as well as hosted payloads on telecom satellites. Principal investigator Natchimuthuk Gopalswamy made good progress in FY13, with a goal to finalize the first compact version in FY14.



This image shows the breadboard 3D imager that Principal Investigator Tony Yu has developed for autonomous rendezvous and docking.

Human Exploration and Operations

Non-Scanning 3D Imager for Autonomous Rendezvous and Docking

One of the pushes in the Human Exploration and Operations line of business is the development of a lightweight, low-power 3D imager for autonomous rendezvous and docking. Principal Investigator Tony Yu used his FY13 IRAD to successfully develop a breadboard non-scanning imaging lidar that he plans to further enhance with FY14 IRAD funding.

Graphene Field-Effect Transistor for Radiation Detection

Graphene, a potentially trailblazing material heralded as the next best thing since the discovery of silicon, could create a new class of ionizing radiation sensors that astronauts could use to warn of exposure to X-rays and charged particles and other potentially harmful space radiation. Under her FY13 IRAD, Principal Investigator Mary Li designed, fabricated, and tested a graphene-based sensor and demonstrated that it was sensitive to gamma rays. Li plans to continue her work under an FY14 IRAD.

This image shows an early incarnation of the Two-Step Laser Tandem Mass Spectrometer for which Principal Investigator Melissa Trainer is developing a miniaturized aerosol-inlet technology.

Planetary and Lunar Science

Particle-Focusing Inlet

In this early-stage effort, Principal Investigator Melissa Trainer is developing a miniaturized aerosol-inlet technology for a next-generation mass spectrometer. According to Trainer, no other organization is focused on analyzing the composition of cloud layers using aerosol time-of-flight mass spectrometry, which this technology would enable. Ultimately, Trainer wants to interface the inlet with a Two-Step Laser Tandem Mass Spectrometer currently under development with NASA R&D funding.

Micro-Machined Thermopile Detectors

Motivated by the need to fly low-mass thermal instruments on missions to the outer planets, Principal Investigator Ari Brown and his team modeled, designed, fabricated, and tested novel micro-machined Bi-Cr thermopile detector arrays. The team believes many NASA missions will benefit from having an in-house capability, including those developing instruments for the proposed Europa Clipper, a fly-by mission to Europa, one of Jupiter's moons (see page 13).

Io Observer Neutral Imaging Camera (IONIC)

Principal Investigator Michael Collier used his FY13 IRAD funding to design and fabricate key parts for the next-generation IONIC instrument, which would allow scientists to observe charge-exchange processes that result in the loss of both mass and energy, for example, in the neutral wind flowing from the Io torus, among other science investigations. The Planetary Science Decadal Survey highlights the need for neutral atom imaging, which IONIC could perform.

Cryogenic Propulsion with Vent-Free Hydrogen Storage for Planetary Science Missions

Cryogenic propellants, such as liquid hydrogen and oxygen, offer superior impulse and could enhance the exploration of the solar system because they offer significant mass advantages over traditional hypergolic propulsion systems. Principal Investigator Shuvo Mustafi used his FY13 IRAD to advance the technology-readiness levels of technologies that would allow the use of cryogenic propulsion and conducted a Mission Design Laboratory study of a mission to the outer planets.

Chapter Six

Culminating a Year of Innovation:
Snapshots of the 2013 IRAD Poster Session

Hundreds of people stopped by to meet and make connections with 99 Goddard principal investigators who presented posters at the Office of the Chief Technologist's annual IRAD Poster Session on Dec. 5. All came to learn more about the cutting-edge technologies Goddard scientists and engineers are pursuing to meet NASA's next-generation technology needs and to make promising connections that could result in successful missions in the future. The Chief Technologist hosts the poster session to increase interactions among the scientific and technical workforce, to identify new areas of application for the technologies developed, to stimulate new collaborations between the disciplines, and explore new opportunities.

Over the course of three hours, this year's IRAD Poster Session attracted hundreds of visitors, as evidenced by this photo taken from the audio/visual skybox overlooking the Building 8 auditorium.

The theme of this year's annual IRAD Poster Session — Goddard Technology: Enabling Science Through Innovation — captured in just a few words the principal goal of the center's Internal Research and Development program. Principal Investigator Semion Kizhner is in the background.

Students from Montgomery County's Bethesda-Chevy Chase High School talk with Principal Investigator Fred Minetto, who has created a novel way to clean mirrors and lenses in clean rooms using a one-atmosphere electron gun whose prototype hardware is displayed on the table.

All images for this section, Photo Credit: Bill Hrybyk/NASA

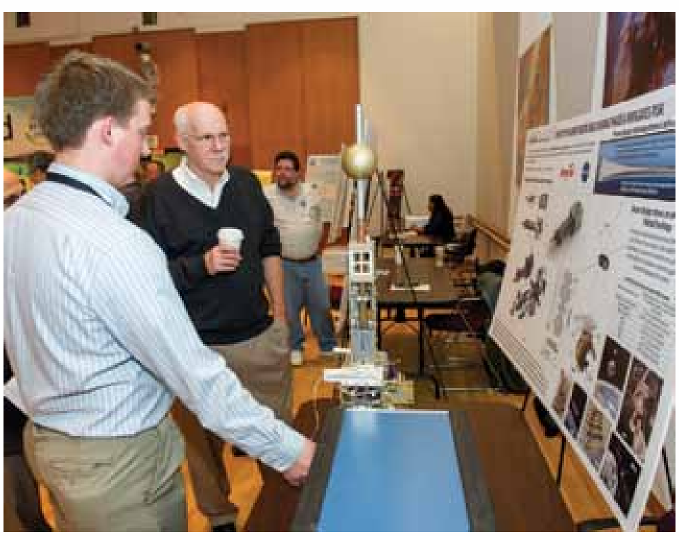
This year, OCT's "IRAD Innovator of the Year" award went to Tom Flatly and the SpaceCube team (from left to right): Tom Flatley, Dave Petrick, Dan Espinosa, Alessandro Geist, Gary Crum, and Mike Linn. Since its flight debut in 2009, the SpaceCube flight processor has evolved into a family of products that offers science missions a much-needed alternative for science-data processing, particularly those requiring more robust computing power to handle significantly higher data rates.

Deborah Amato, Goddard Deputy Chief Technologist, Azita Valinia, Associate Director for Research and Development for Goddard's Sciences and Exploration Directorate, and Jim Adams, NASA's Deputy Chief Technologist, talk technology and share a laugh.

Stan Hooker (left) and John Morrow, president of the San Diego-based Biospherical Instruments Inc., are developing a low-light radiometer that can reliably measure light levels that are about one million times dimmer than the light level from the full Moon. The instrument would allow scientists to gather measurements at night or under low-light conditions — a critical need for scientists studying the polar-regions during the winter months when daylight hours are much shorter. Components of that instrument are displayed on the table.

Principal Investigator Luis Santos Soto (left) used FY13 IRAD funds to build the Diminutive Assembly for Nanosatellite deploYables mechanism to release smallsat solar panels and antennas. At 0.188 inches, it is the only all-in-one system that fits into the external-volume allocations of CubeSats, saving valuable internal space for other subsystems. He is shown here with Scott Hesh, the electrical engineer on the project.

Principal Investigator Joe Nuth (left) explains to NASA Deputy Chief Technologist Jim Adams the sample-retrieval system he is developing under his IRAD funding.



Principal Investigator Robert Pfaff (background) stands next to the prototype of an electric field boom that he developed for the Atmosphere-Space Transition Region Explorer (ASTRE). Although NASA did not select the ASTRE concept during the last Explorer Call for Proposals, Pfaff is fine-tuning the 10-meter boom. An earlier version of the boom now flies on a U.S. military satellite.